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DECISION SUPPORT SYSTEM (DSS) FOR DOMESTIC WELL-WATER TREATMENT PLANT INSTALLATION

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ABSTRACT

Quality water for human consumption is germane to living healthy. This has led to individuals and communities sinking borehole in their homes and communities. Due to Naira devaluation, the cost of boreholes installation has increased beyond their reach. Therefore, this study employed the usage of domestic well water treatment as a means of quality water production for human consumption. A plant of 6,000 liters capacity was designed and installed. An estimated cost of each unit, the labor involved, interest rate of capital involved, possible units and their components and due date determination for the project were done. Decision Support System (DSS) written in JAVA Programming Language was developed for easy computation and decision making. This decision support system was tested and validated using a case study. The estimated cost for the whole project in this study was N465,000 compared with the installation of the borehole of 1.5 million Naira (N1,500,000). This project caused a reduced cost of 69%. The due date for the project was predicted to be 97 days but the project was completed in 92 days, which showed that the effectiveness is 94.85% and risk involved in this project to be 5.15%.

KEYWORDS: Decision Support System, Well Water Treatment; JAVA Software, Due-date Prediction & Model Development

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1. INTRODUCTION

Water is one of the most common substances known. It is a good solvent for many substances and rarely occurs in its pure form in nature [1, 2]. Natural water includes rainwater, spring water, lake water, river water, well-water and seawater [3]. These can be grouped into either surface water which includes streams, rivers, lakes or reservoirs; and groundwater such as springs, wells or boreholes. Well-water is a groundwater source that sometimes contains a lot of clay and other mineral salts. To avoid underground water pollution, well as a source of drinking water should be sited away from the latrine and lined with bricks and covered. Water is essential to man, plants, and animals [2, 4, 5]. However, in Africa, the availability of good and potable water is scarce. The quality of life and its household community can significantly improve when a better water supply is provided [6]. The origin and history of water have a serious impact on the quality of the water. Natural water shows, in general, qualities characteristics of their sources. However, climatic, geographic and geologic conditions all play important parts in determining water quality [7].

In developing countries, insufficient or unsafe water alongside with local factors such as climate, population density, and local practices have been attributed to the outbreak of some diseases in poor or developing countries [8–9]. To control these diseases, a sufficient amount of safe drinking water is important. Hence, improvement of the design and planning of water supplies matters as well as sanitation and hygiene behavior. Water

purification is the process of removing undesirable materials, chemicals, biological contaminants, suspended solids and gases from contaminated water. Water purification is designed for a variety of purposes such as human consumption, meeting the requirements of medical, pharmacological, chemical and industrial applications [10]. Filtration, sedimentation, and distillation are the physical processes; slow sand filters or activated sludge are the biological processes; flocculation and chlorination are the chemical processes, and the use of electromagnetic radiation such as ultraviolet light is the processes involved in water purification [11].

In tropical countries, water consumption tends to be high and if there are high seasonal temperature variations, the demands will be higher [12]. The amount of expertise, the cost of labor and the availability of materials for sinking hand dug-well are of importance. There is a need for a model that will assist project managers and engineers in planning for well-water treatment plant installation, elimination of shortage or wastage of materials, reduce the labor time, under-utilization or over-utilization of manpower and machines with regards to the domestic well water treatment plant project. In essence, there is a need for a model that will assist the project engineer in achieving shortest possible time for cost computation of the Bill of Engineering Measurement and Evaluation (BEME) as well as due date prediction for the project.

This study was aimed to develop a model for predicting the domestic well-water treatment plant project due-date and to estimate the cost of the plant installation. Hence, the required activities for domestic well-water treatment plant were investigated and mathematical models developed. Moreover, simple framework software for the model using JAVA Programming Language was developed and evaluation of the performance of the developed model was done. A decision support system capable of predicting domestic well-water plant installation, due-date, risk values, and cost estimation during the project planning phase was made available.

2. MATERIALS AND METHODS

This study involves a comprehensive analysis of domestic well-water treatment plant in order to carry out its design analysis and its layout; identify the components required for this system to be able to obtain the required historical information; identify all the activities involved to be able to determine the due date; carry out the market feasibility study to be able to give the materials estimation; develop a mathematical model for the required calculations based on the historic information collected; development of software for the model implementation; and application of the developed software Decision Support System (DSS) for result generation using the historic information/ data available.

2.1 Design Analysis

The design analysis of this study involves: determination of the domestic well-water plant capacity, developed a layout for the domestic well-water plant, ascertain the sub-units and material required, determine the mathematical models required for due date and cost estimation prediction, conduct the market price analysis for each sub-unit identified, develop the required software for the cost prediction and, application of the developed software for decision making.

The activities required in domestic well-water treatment plant development are feasibility study; design plan, materials selection/cost estimation, construction layout, well-digging preparation, component assembly, test-run of the system, and commissioning.

The pumping time (PT) was obtained from the plant capacity (PLC) which was 6000 liters and pumping rate (PR) which was 3.5 m^3/h to be 1.71 h (i.e. 1 hour 43 mins). The approximate volume of water consumed per day by the entire

household was obtained to be 8114 liters using a well submersible pump of 1 h.p. capacity, to transfer well water into the water tank.

The major processing units were arranged in this order and contain the following components: well-water unit, dosing unit, pressure filter unit, and retention tanks. Appendix 1 shows the various units.

2.2 Model Development

Due-Dates Model

The activities to be carried out, expected time and variance of the water treatment plant are displayed in table 1.

Table 1: Activities, Expected Time and Variance Computation in Domestic Well-water Treatment Plant

Sl. No.	Activity	Preced. Activity	Activity Description	A Optimistic Time	B Most likely Time	C Pessimist Time	Expected Time E_T	Variance
1	A	-	Feasibility Study: Site identification and geophysical survey	2	4	6	24/6 = 4	0.4444
2	B	-	Design Plan	11	7	15	54/6 = 9	0.4444
3	C	A, B	Materials Selection/Cost Estimation	2	5	8	30/6 = 5	1
4	D	B, C	Construction Layout	3	6	9	36/6 = 6	1
5	E	B, D	Well digging	4	8	12	48/6 =8	1.7777
6	F	C, D	Component Assembly	2	3	4	18/6 = 3	0.1111
7	G	E, F	Test-run of the System	5	7	9	42/6 = 7	0.4444
8	H	G	Commissioning	1	2	3	12/6 = 2	0.1111

The data collected in Table 1 were used for computing the Expected Time "ET", Variance "V", Standard Deviation "SD" and Probability of Success "Z" of the date, respectively. The PERT network of the project obtained from table 1 is given in figure 1.

Project Network

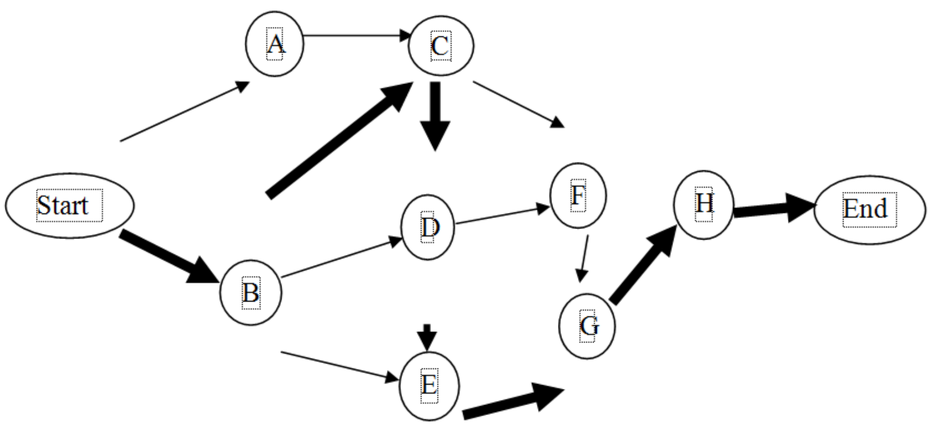

Figure 1: PERT Network of the Project.

The determination of the critical path is done by computing each path duration from table 1 and figure 1. The following underlisted paths were possible to be able to find the critical path for these activities. These paths are A = 4, B = 9, C = 5, D = 6, E = 8, F = 3, G = 7 and H = 2.The highest value for the project completion due-date was selected.

Table 2: Critical Paths Analysis for the Project Completion Due Date

Sl. No.	Activity's Paths	Procurement Activities	Total
1.	A→C→F→G→H	4 + 5 + 3 + 7 + 2	21
2.	A→C→D→F→G→H	4 + 5 + 6 + 3 + 7 +2	27
3.	A→C→D→E→G→H	4 + 5 + 6 + 8 + 7+ 2	32
4.	B→C→F→G→H	9 + 5 + 3 + 7 + 2	26
5.	B→C→D→F→G→H	9 + 5 + 6 + 3 + 7 + 2	32
6.	**B→C→D→E→G→H**	**9 + 5 + 6 + 8 + 7 + 2**	**37**
7.	B→D→E→G→H	9 + 6 + 8 + 7 + 2	32
8.	B→D→F→G→H	9 + 6 + 3 + 7 + 2	27
9.	B→E→G→H	9 + 8 + 7 + 2	26

Total Paths = 9

To determine the expected completion time for these procurement activities, all the time attached to each activity on the paths were added together and compared. The path with the longest time is the expected completion time for the procurement activities. Equations (1)–(5) were used to determine the expected time (ET), variance (V), standard deviation (SD) and probability of success (Z) of the date, respectively.

For Expected Time, "E_T" = $\frac{O_t + P_t + 4ML_t}{6}$ (1)

For the Variance, "V" = $[\frac{P_t - O_t}{6}]^2$ (2)

For the Standard Deviation, "δ" = $\sqrt{\sum_{i=1}^{n} V}$ (3)

To find the Total Number of Period, "T_P" = $E_T + V$ (4)

For the Normal Variant of Scheduled Time "Z", "Z" = $\frac{(T_P - E_T)}{V}$ (5)

From table 2, the expected completion time, E_T = 37 days (sum of critical path), and the standard deviation was calculated to be 2.2 days.Total Expected Date (TED) = Expected Completion Time (TED) + Variance (VT) = 39.2 days. This is the latest date for project completion while the earliest date for completion is 37 – 2.2 = 34.78 days. Hence, the probability that the domestic well-water will be completed in days between 34.78 and 39.2 days is (Eq. (5)):

$$Z = \frac{T_{ED} - E_T}{V} = \frac{39-37}{2.2} = \frac{2}{2.2} = \quad 0.909090$$

Z_n = 34.23%

This is the probability of success of this project. However, this is unacceptable since the risk involved is 65 .77%. The new acceptable due-date was predicted by simulation with the mind of 90% success and 10% risk thus:

$$Z_{nx} = \frac{\% \times E_T}{Z_n}$$

Therefore, $Z_{nx} = \frac{90 \times 37}{34.23} = \frac{3330}{34.23}$ = 97.28 days.

Therefore, the system was simulated and the new completion date was obtained to be 97.28 days.The risk involved now reduced to 10% which is in a very good comfort zone for the project.

Cost Model Development

The cost model considered were for the well-water unit, pressure filter, dosing, clean water tank, material installation and labour cost.

Nomenclature

Q is quantity of each item

P is price per unit item

T_p is total price of a set of similar components

EC is estimated cost of the whole project.

TE is total estimate to be charged by contractor.

TC is total cost of the major components.

IR is interest rate (percentage) = (n%)

$U_{1\text{-}6}C$ is total cost of the whole processing unit with labour and other miscellaneous expenses.

U_1C is cost of components in processing unit 1 (Well-Water Unit)

U_2C is cost of components in processing unit 2 (Pressure Filter Unit)

U_3C is cost of components in processing unit 3 (Dosing Unit)

U_4C is cost of components in processing unit 4 (Clean water Tank Unit)

U_5C is material installation cost

n is the number of items

U_6C is cost of labour

The general model for the total price of a set of similar components, total cost of major component and total cost of the whole processing unit with labour and other expenses were given in Eqs. (6)–(8).

$$T_p = Q_i \times P_i = q_1p_1, q_2p_2, q_3p_3, \dots\dots q_np_n \tag{6}$$

$$TC = [\textstyle\sum_{i=1}^{4} q_ip_i] = q_1p_1 + q_2p_2 + \dots . + q_4p_4 \tag{7}$$

$$U_{1-6}C = [\textstyle\sum_{i=1}^{n} q_ip_i] = [\sum_{i=1}^{n} q_1p_1]u_1 + [\sum_{i=1}^{n} q_1p_1]u_2 + \dots [\sum_{i=1}^{n} q_1p_1]u_n \tag{8}$$

The cost of each unit as well as material installation and labour costs were obtained using Eqs. (9) – (14).

Cost of Well-Water Unit Components

$$U_1C_1 = [pq]_{11} + [pq]_{12} + [pq]_{13} + [pq]_{14} + [pq]_{15} + [pq]_{16} + [pq]_{17} + [pq]_{18} + [pq]_{19} = [\textstyle\sum_{i=1}^{9} q_1p_1]u_1 \tag{9}$$

where $[qp]_{11}$ to $[qp]_{19}$ are:Pumping machine, PVC conduit pipe, valve fitting, socket fitting, elbow fitting, union fitting, well submersible pump, marine rope and T-fitting cost, respectively.

Cost of Pressure Filter Unit Components

$$U_2C = [pq]_{21} + [pq]_{22} + [pq]_{23} + [pq]_{24} + [pq]_{25} = [\sum_{i=1}^{5} p_i q_i]u_2 \quad (10)$$

where $[pq]_{21}$ to $[pq]_{25}$ are: Filter tank, activated carbon, fine sand, coarse sand and gravel, respectively.

Cost of Dosing Unit Components

$$U_3C = [qp]_{31} + [qp]_{32} + [qp]_{33} = [\sum_{i=1}^{3} q_i p_i]u_3 \quad (11)$$

where $[qp]_{31}$ to $[qp]_{33}$ are: Dosing pump, chemical solution tank and chlorine drum costs, respectively.

Cost of Retention Water Tanks Unit Components

$$U_4C = [qp]_{41} + [qp]_{42} = [\sum_{i=1}^{2} q_i p_i]u_4 \quad (12)$$

where $[qp]_{41}$ and $[qp]_{42}$ are: Clean water tank and raw water tank costs (retention tanks), respectively.

Cost of Material Installation (MIC)

$$U_5C = [qp]_{51} + [qp]_{52} + [qp]_{53} + [qp]_{54} + [qp]_{55} = [\sum_{i=1}^{5} q_i p_i]\, u_5 \quad (13)$$

where $[qp]_{51}$ to $[qp]_{52}$ are: Electric cable, electric switch, tipper of sharp sand, tipper of granite and a bag of cement costs, respectively.

Cost of Labour Cost (LC) Components

$$U_6C = [qp]_{61} + [qp]_{62} + [qp]_{63} + [qp]_{64} = [\sum_{i=1}^{4} q_i p_i]\, u_6 \quad (14)$$

where, $[qp]_{61}$ to $[qp]_{64}$ are: Cost of plumbing labour, masonry labour, cost of electrical labour, and miscellaneous expenses, respectively.

$$U_{1-6}C = [\sum_{i=1}^{6} q_i p_i]u_{1-6} = [\sum_{i=1}^{6} U_i C] = U_1C + U_2C + \ldots\ldots U_6C \quad (15)$$

The interest rate (IR), estimated cost of the whole project (EC) and total estimate to be charged by contractor (TE) were obtained using Eqs (16)–(18), respectively.

$$IR = n/100 \quad (16)$$

$$EC = [\sum_{i=1}^{6} q_i p_i]\, u_{1-6} + TE \quad (17)$$

$$TE = [\sum_{i=1}^{6} q_i p_i]u_{1-6} \times IR \quad (18)$$

3. RESULTS AND DISCUSSIONS

The activities ascertained for the domestic well-water treatment plant are feasibility studies, design plan, materials selection/cost estimation, construction of the plant layout, well-digging, component assembly, test run of the system and commissioning. The parameters determined for decision making are the pumping power, pumping rate, tank capacity while the parameters for the due-date prediction; expected time, variance, standard deviation and total number of periods; were determined as well as the probability on the project completion successful and risk involved. Materials required were identified and cost analysis carried out which are well-water unit components, pressure filter, and dosing unit, retention tanks, materials installation cost, and cost of labour.

3.1 Software for Model Developed using JAVA Programming

The software model was developed using JAVA programming language. The interface was developed using Java programming language swing utilities which comprise mostly of J-Frames, J-Text fields and J-Buttons for the main controls. Action listeners and action events were used to control the button functionalities, handle calculations and panel displays.

The home interface for the software developed is as shown in figure 2. The cost estimation and due dates can be obtained using this software. Figures 3–9 display various interfaces of the software and operation procedures were stated.

Figure 2: Software Application for Decision Making (Software Demonstration).

Operation: Click the buttons to enter the desired option to perform cost estimation or due date.

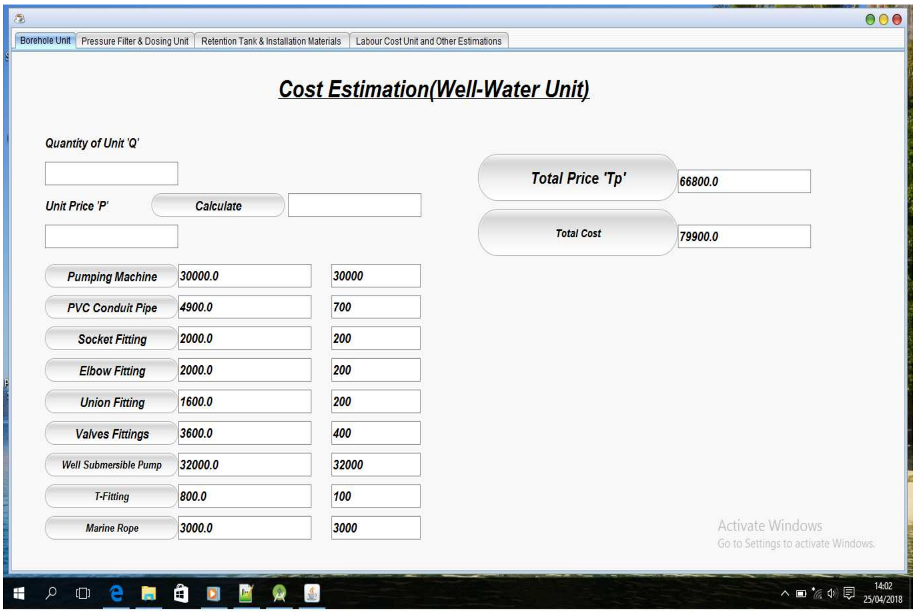

Figure 3: Interface Result for Well-Water Unit (Cost Estimation).

Operation: Enter the values of unit and the price then press calculate. Then click the buttons in each unit to display their values. Click the total price and the total cost buttons to also display their values.

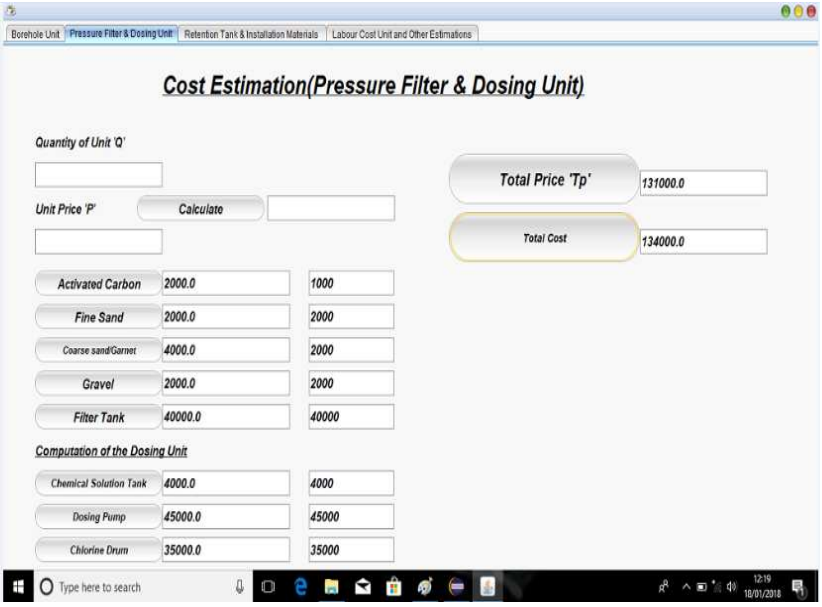

Figure 4: Interface Result for Pressure Filter and Dosing Unit (Cost Estimation).

Operation: Enter the values of unit and the price then press calculate; then click the buttons in each unit to display their values. Click the total price and the total cost buttons to also display their values.

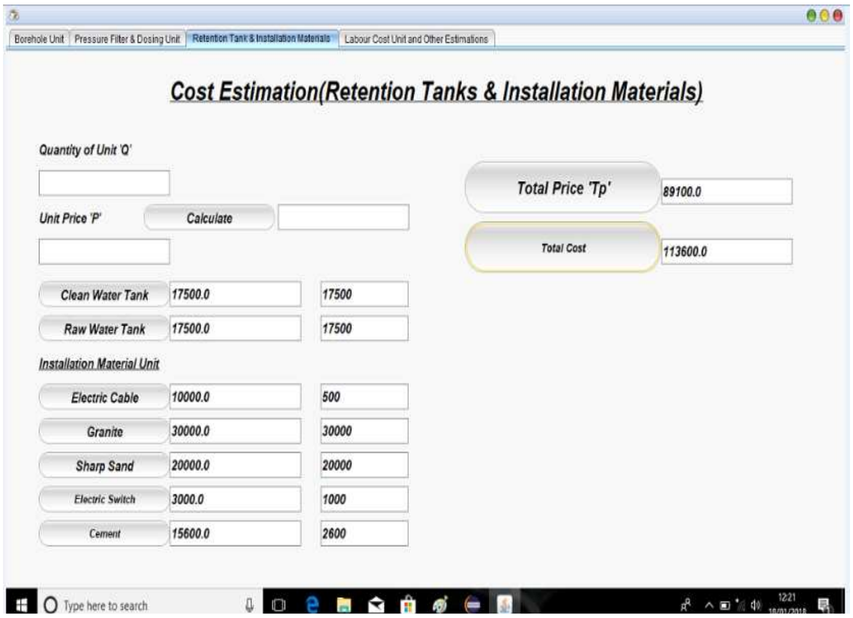

Figure 5: Interface Result for Retention Tanks and Materials Installation (Cost Estimation).

Operation: Enter the values of unit and the price then press calculate; then click the buttons in each unit to display their values. Click the total price and the total cost buttons to also display their values.

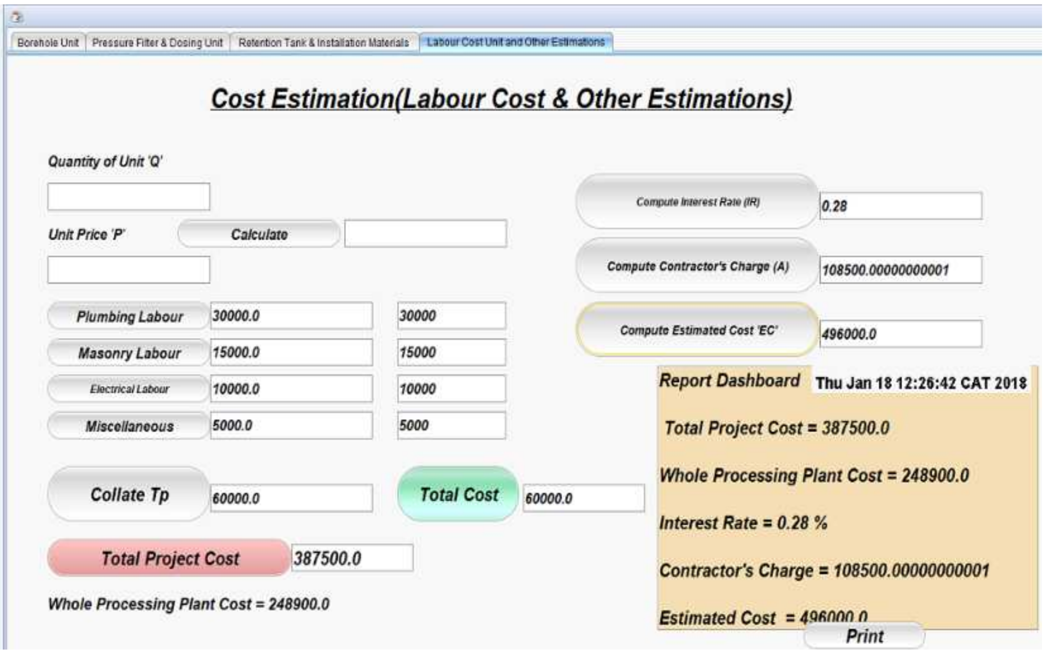

Figure 6: Interface Result for Labour Cost and Other Estimations (Cost Estimation).

Operation: Enter the values of unit and the price then press calculate. After, click the buttons in each unit to display their values. Click the total price and the total cost buttons to also display their values. Click the interest rate, contractor's charge and estimation cost buttons to display their values and print the results.

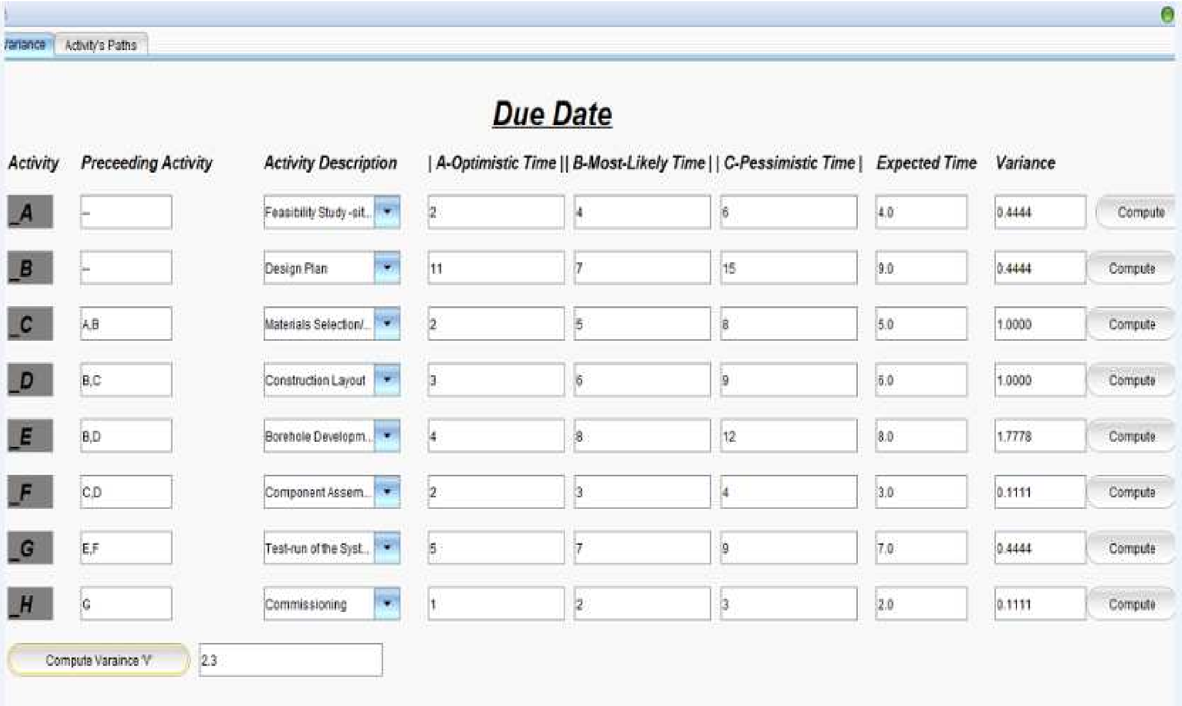

Figure 7: Interface Result for Expected Time and Variance.

Operation: Choose the activity description and enter the values of optimistic, most likely and pessimistic time then click compute to calculate. Click the compute variance button to calculate variance.

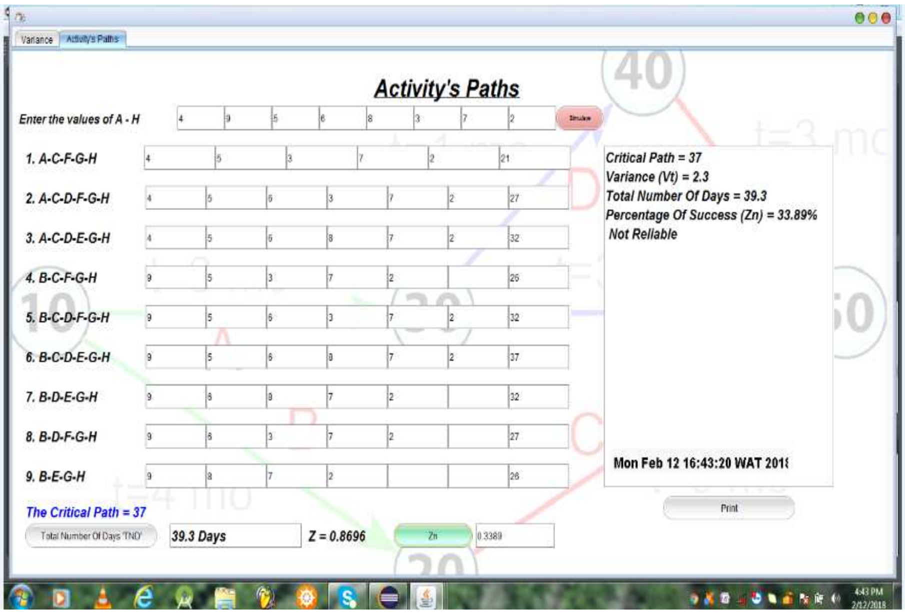

Figure 8: Interface Result for Critical Path and Due Date Prediction.

Operation: Enter the values of A-H then click the stimulate button to create the table and critical path. Click the total number of days (TED) button to get the total number of days and the Zn button to compute the results. The print button helps to print the result in the display. Here, the percentage of success of this project was at 33.89% as too low and shows a risk of 66.11%. This needs to be controlled using the next interphase in figure 9.

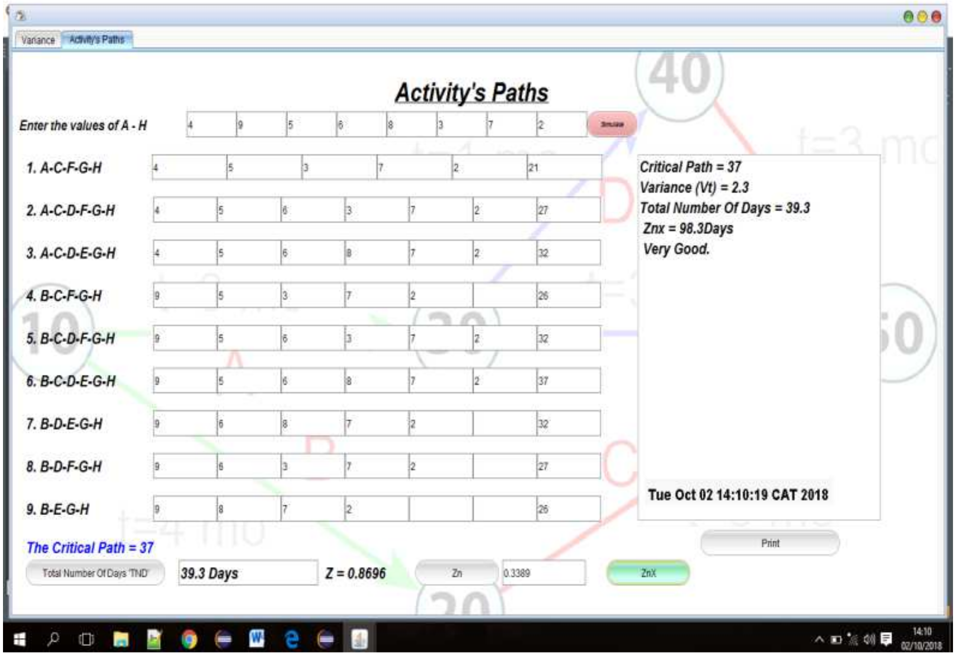

Figure 9: Control Interphase for Improving on the Low Success and High Risk That Emerged.

In figure 9, the risk and the possibilities of success were put at 5.15% and 94.85%, respectively. Backward computation was carried out which gave a new due date of 97 days.

3.2 Efficiency Determination of Decision Support System (DSS)

To determine the effectiveness of DSS developed, the actual number of days (AD) used for the project completion was used as numerator while the due date predicted (DP) as the denominator and multiplied by 100%.

$$\sum f = \frac{AD}{DP}\ x\ 100\ (where\ AD = 92;\ and\ DP = 97).$$

$$\sum f = \frac{92}{97}\ x\ 100 = 94.85\%$$

3.3 Case Study: Household Community

In this study, all relevant and applied data used were obtained from a house making use of this facility or plant system. This house is located in Akure, Ondo State, Nigeria. This house is a storey building of 23 occupants of four flats. Each flat has 3-bedrooms and the house has one boy's quarters (BQ). A schematic diagram of the well water plant is displayed in figure A1 (Appendix).After the model development, each unit cost was computed and values obtained are displayed in tables 3–8.

Table 3: Computation of the Well-Water Unit [U_1] Cost

Sl. No.	Components	Unit Price (p_i)	Quantity (q_i)	Total Cost (₦)
1	Pumping Machine	30000	1	30000
2	PVC Conduit Pipe	700	7	4900
3	Socket Fitting	200	10	2000
4	Elbow Fitting	200	10	2000
5	Union Fitting	200	8	1600
6	Valves Fittings	400	9	3600
7	Well Submersible Pump	32000	1	32000
8	T-Fitting	100	8	800
9	Marine Rope	3000	1	3000

$U_1C\ [\sum_{i=1}^{9} q_i p_i]u_1 = 79900$

Table 4: Computation of the Pressure Filter Unit [U_2] Cost

Sl. No.	Components	Unit Price (p_i)	Quantity (q_i)	Total Cost (₦)
1	Activated Carbon	1000	2	2000
2	Fine Sand	2000	1	2000
3	Coarse sand/Garnet	2000	2	4000
4	Gravel	2000	1	2000
5	Filter Tank	40000	1	40000

$U_2C\ \left[\sum_{i=1}^{5} q_i p_i\right]u_2 = 50000$

Table 5: Computation of the Dosing Unit [U_3] Cost

Sl. No.	Components	Unit PRICE (p_i)	Quantity (q_i)	Total Cost (₦)
1	Chemical Solution Tank	4000	1	4000
2	Dosing Pump	45000	1	45000
3	Chlorine Drum	35000	1	35000

U_3C $\boldsymbol{\left[\sum_{i=1}^{3} q_i p_i\right]u_3 = 84000}$

Table 6: Computation of the Retention Tanks Unit [U_4] Cost

Sl. No.	Components	Unit Price (p_i)	Quantity (q_i)	Total Cost (₦)
1	Clean Water Tank	17500	1	17500
2	Raw Water Tank	17500	1	17500

U4C	$\left[\sum_{i=1}^{2} q_i p_i\right] u_4$	=	35000

Table 7: Computation of the Material Installation (MI) [U_5] Cost

Sl. No.	Components	Unit price (p_i)	Quantity (q_i)	Total Cost (₦)
1	Electric Cable	500	20	10000
2	Granite	30000	1	30000
3	Sharp sand	20000	1	20000
4	Electric switch	1000	3	3000
5	Cement	2600	6	15600
	U_5C	$\left[\sum_{i=1}^{5} q_i p_i\right] u_5$	=	78600

Table 8: Computation of the Labour Cost (LC)[U_6]

Sl. No.	Components	Unit Price (p_i)	Quantity (q_i)	Total Cost (₦)
1	Plumbing Labour	30000	1	30000
2	Masonry Labour	15000	1	15000
3	Electrical Labour	10000	1	10000
4	Miscellaneous Expenses	5000	1	5000
	U_6C	$\left[\sum_{i=1}^{4} q_i p_i\right] u_6$	=	60000

The total cost of the major components is the summation of the first four units cost, that is, the summation of the cost on Tables 3–6 which was obtained to be ₦248900. Moreover, the whole processing plant cost using Eq. (15) was calculated to be ₦387500.

3.4 Determination of Total Estimate using the Interest Rate (IR)

As at the time of this study, interest rate (IR) in the bank for taking any estimate cost (EC) was 20%. Therefore, the total estimate (TE) of interest was derived to be ₦77500 using Eq. (17) while the estimated cost was calculated using Eq. (18) and the value obtained was ₦465000. This implied that the estimated cost for the entire project was Four hundred and sixty-five thousand Naira (₦465000) in which the equivalent Dollar price was One thousand, five hundred and twenty-two Dollars (USD 1522) at the rate ₦360 per Dollar as at the time of study.

3.5 Determination of Percentage Contribution of Each Unit of the Total Estimate

Equation (19) was used in the determination of the percentage contribution of each unit. It is the estimate for each unit divided by the total estimate multiplied by hundred.

For any unit, $Ui = [UiC]/EC \times 100\%$ (19)

Based on the values obtained, the summary of each unit contribution and the statistical analysis required for clarity, meaningful explanation is shown in figure 10.

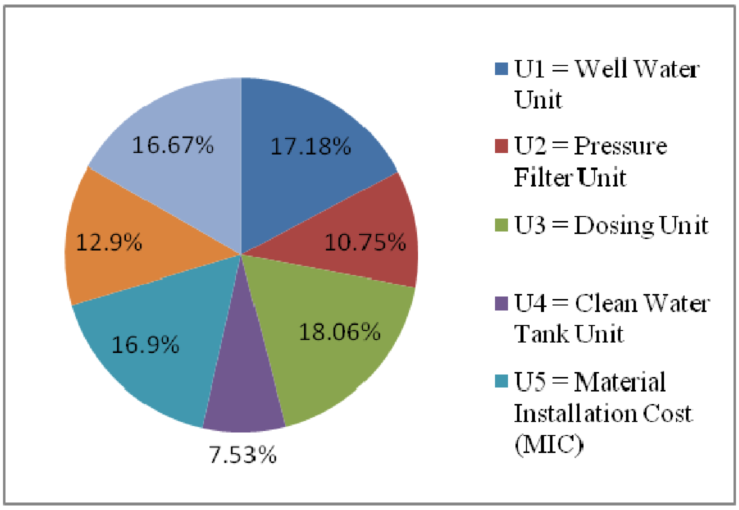

Figure 10: Percentage Contribution of Each Component in Total Cost Estimate.

This percentage contribution of each unit is essential for determining the area of negotiating down the price of material, to reduce the total cost of the domestic well water treatment plant installation. Based on the summary results, dosing unit was observed to have contributed to the highest cost percentage followed by well-water unit, material installation cost, interest rate of borrowed investment, labour cost, pressure filter unit and clean water tank unit with values 18.06, 17.18, 16.9, 16.67, 12.9, 10.75 and 7.53%, respectively. The dosing unit, well water unit, material installation cost and interest rate of the total estimate should be an area of strong focus for cost reduction. The main criteria required for domestic well water treatment plant installation which are the cost of installation and due-date for the project have been identified in this study. A simple costing model for predicting the construction cost of the domestic well water treatment plant was built. The total cost (TC) for each set of identical components was obtained to be N248900. The total cost is also summed up to get the cost of each processing plant. The total cost U1-6C of the whole project is also derived by summing together the total cost for major components, labour, and other material installation expenses. The estimated cost (EC) gives the overall total cost of embarking on the project. It is the summation of the charge (TE) by the contractor and the total cost of the whole project (U1-6C). These gave a total estimate of N465000 for the project (USD 1522 at an exchange rate of N360 per Dollar).

DSS software was developed using JAVA Programming Language and the interface due to its flexibility and form as an Object-Oriented Programming Language (OOPL) and the fact was a cross-platform programming language that can run on any form of Microsoft Operating System (MOS). The developed software model was evaluated using data obtained from a building site as a case study.

4. CONCLUSIONS

This study has identified the parameters for budgeting and strategic decisions for domestic well-water treatment plant installation. Mathematical models based on historical information collected were harmonized to generate an algorithm. The algorithm was then used to develop a computer software on the JAVA programming language platform, which was tested for efficiency and accuracy using a domestic well-water treatment plant as a case study. The study has provided an effective planning system for domestic well-water project development. This has been done to avoid project failure, maximize limited budget available and minimize cost. On the overall, the software that was developed can be used by

construction consultants, project managers and site engineers to estimate the cost prediction and due date of domestic well-water treatment plant installation project. The software was found to be reliable and cost-effective in terms of time and financial resources, thereby increasing the production of its users.

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APPENDIX

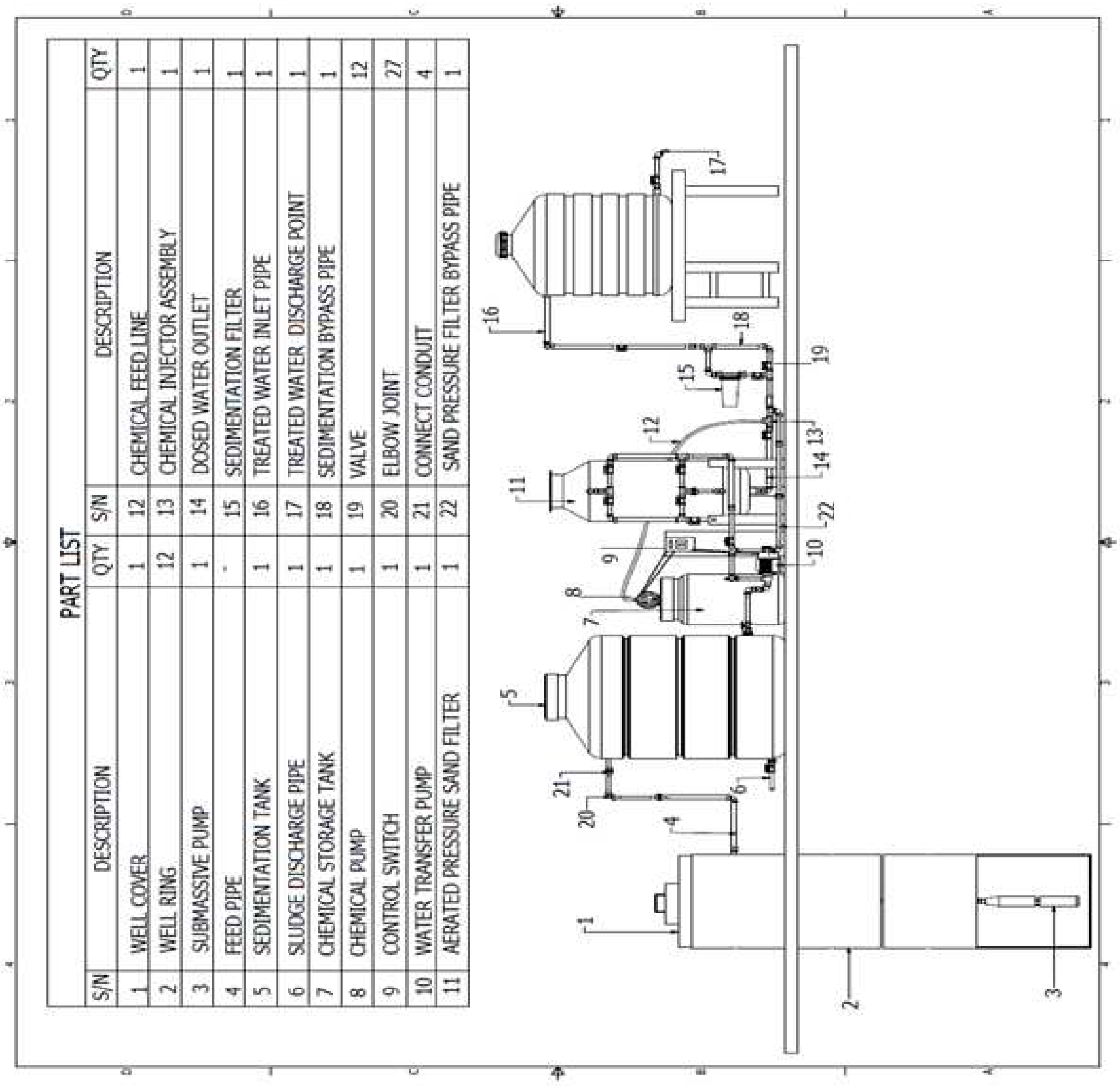

Figure A1: A Schematic Diagram showing the Layout of Domestic Well-Water Treatment Plants Installation.

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